Studies of the SPS internal dump (TIDVG) for current and future proton beams

Alexander Stadler – EN/STI/TCD
SPSU Meeting
4th of August 2009
Outline

- A brief overview – The TIDVG & previous study
- Vacuum outgassing problems during operation
- Performance with current proton beams
- Performance with PS2 beams
- A slightly modified design
- Conclusion and different scenarios
Previous study

• Conducted by Mattias Genbrugge and presented to SPSU in 2008 by Yacine Kadi
  – Researching the history of the present dump design
  – Exploring causes of the outgassing issue

• This presentation
  – will follow up on the outgassing issue
  – will present the operation limits of the dump (current + PS2 beams)
The TIDVG

• The Target Internal Dump Vertical Graphite
  – For energies from 105 to 450 GeV
  – Located in LSS1
  – About 5m long; Core diameter 0.3 meters
  – Installed in cast iron shielding
The TIDVG design

• An internal beam dump
The TIDVG design

2.5m Graphite
1m Antico
0.5m copper
0.3m Tungsten

Graphite blocks:
Titanium coating +
Titanium foil

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TIDVG study
The TIDVG History

• Three Dumps Produced
  – Dump #1 installed in 1999/2000
  – Foil got Damaged and was blocking the aperture
  – Dump #2 was modified (better coating – no foil)
  – Dump #1 replaced by #2 in 2006/2007

  – Dump #3 was not modified (not ready as spare at the moment)
  – Dump #1 Out of order – In Storage (radioactive)
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• A brief overview – The TIDVG & previous study
• **Vacuum outgassing problems during operation**
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II. Operational Problems

After commissioning in March 2000:

- Pressure peaks from the moment the beam was dumped.

(Repetitive dumping of $9 \times 10^{12}$ protons per cycle at 440 GeV.)

Consequence:

$=>$ Shutdown of the beam due to pressure interlock system.
Possible causes
(as presented in 2008)

• Outgassing originating from: Tungsten or Graphite blocks (Antico and copper are solid metals)

• Outgassing is driven by
  – Temperature
  – Internal concentration of pollutants

• Pressure rise due to e-clouds (presented with a ?)
  – “No proof! Only hints:”
  – “It is inconclusive until now, but it seems not very likely.”
Looking for the cause of the outgassing

• Significant steps during production and installation of the Dump:
  – Vacuum firing of the graphite (1000°C for 1h) before assembly & welding
  – Bakeout with pressurized water @ 150°C
    • After complete assembly & welding (on surface)
    • After installation (in the tunnel)
Looking for the cause of the outgassing

- **Significant observations and actions after installation**
- Dump #1 got conditioned in-situ with beam scraping during MDs
  - Rising the temperature of the Dump and causing the outgassing on purpose (beam scraping)
  - The outgassing rate of the dump got less over time
  - Every dump-cycle is improving the dump (less outgassing)
- After installation of Dump #2 the outgassing during dumps was again high.
  - Dump #2 now in use for ~2 years
Looking for the cause of the outgassing

- Performing a bakeout test in the lab to answer the questions:
  - Is the current bakeout temperature sufficient?
  - How big is the outgassing due to high temperatures?
    - Outgassing of water and/or hydrocarbons?
    - Which material (Graphite or Tungsten) is the origin?

Tests performed with support from TS/VSC for setting up the vacuum & bakeout equipment.
Bakeout test on Dump #3

Recording:
- Pressure
- Gas composition
- Temperature (in the vacuum directly on the blocks)

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Bakeout test on Dump #3

• Initial conditions:
  – Dump was stored under gas atmosphere (like a proper spare, although not ready to use as spare yet)
  – Dump got opened up and exposed to atmosphere for several months to get a full absorption of water
1\textsuperscript{st} long Bakeout cycle

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2nd full cycle to get comparative measurements
Spectrum at RT between 1\textsuperscript{st} and 2\textsuperscript{nd} cycle

Pressure 1.1E-8 mbar
RGA spectrum @ 150°C

Temperatures in Celsius
Graphite: 147
Antico: 147
Copper: 143
Tungsten: 140
Copper core: 149

Pressure 4.0E-7 mbar

H2O

CxHx

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RGA spectrum @ 200°C

Temperatures in Celsius
Graphite: 193
Antico: 194
Copper: 187
Tungsten: 183
Copper core: 196

Pressure 2.1E-6 mbar

H2O

CxHx

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RGA spectrum @ 250°C

Temperatures in Celsius
Graphite: 246
Antico: 244
Copper: 238
Tungsten: 230
Copper core: 245

Pressure 1.7E-5 mbar

H2O

CxHx

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Selective heating of graphite and tungsten

Tungsten  Copper  Antico  Graphite
RGA spectrum with graphite @ 250°C; rest @ 150°C
RGA spectrum with Tungsten @ 230°C; rest @ 150°C

Pressure 2.5E-6 mbar

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Conclusion – Outgassing issue

- Graphite still shows a lot of outgassing after vacuum firing before assembly, and an intense bake out (25 days at 150°C+)
- The present hydrocarbons indicates that the vacuum firing done before assembly was not sufficient!
- Hydrocarbons can not be removed by baking out the graphite in the dump (temperature limitation of the copper core)
- Tungsten seems to be clean from hydrocarbons
- Still a lot of water outgassing present at high temperatures
  - Required time for a water bake out needs to be determined
  - Tests on diffusion coefficient of water in Graphite currently being prepared by TE/VCS Giovanna Vandoni & Florent Bouvier
- Current bakeout @ 150°C is sufficient for water
Proposed actions for dump #3

• Assuring a low outgassing rate of the graphite at high temperatures before assembling the Dump (testing !)
  – When modifying dump #3 cleaning the Graphite blocks with an long vacuum firing (1000°C+ for many hours!) to reduce hydrocarbons

• long bakeout for removing the water (on surface)

• Keep contact with atmosphere as short as possible!
  – Isolating valves for the dump?
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Previous simulations conducted by Mattias Gebrugge

- The goal was to determine the temperature in the materials after a few consecutive dumps
- This information was used to assess if the bakeout temperature (150°C) is sufficient

- The new studies are to determine the limits of the dump during operation!
Determining the performance of the TIDVG

- 3D thermal simulation in ANSYS
- Energy deposition in FLUKA (supplied by Roberto Rocca)
- Beam characteristics & dumping patterns

<table>
<thead>
<tr>
<th></th>
<th>LHC ultimate</th>
<th>CNGS</th>
<th>PS2_LHC</th>
<th>PS2_CNGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total intensity</td>
<td>4.90E+13</td>
<td>4.80E+13</td>
<td>7.00E+13</td>
<td>1.20E+14</td>
</tr>
<tr>
<td>Energy [GeV]</td>
<td>450</td>
<td>400</td>
<td>450</td>
<td>400</td>
</tr>
<tr>
<td>Repetition time [sec]</td>
<td>21.8</td>
<td>6</td>
<td>4.8</td>
<td>4.8</td>
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</table>
Simulations

• 4 extreme scenarios
  – Continuous CNGS-Beam dumping
  – Continuous LHC-Beam dumping
  – Continuous PS2_CNGS-Beam dumping
  – Continuous PS2_LHC-Beam dumping
  – Each one followed by 5 minutes cooling
• Comparison of maximum protons/second to reach steady state
• Limit: Temperature of the Antico (aluminum) should not exceed 450°C!
Continuous CNGS-Beam dumping maximum 23 cycles

CNGS - old design

Temperature [°C] vs Time [s]

- Copper_core
- Graphite
- Antico
- Copper_block
- Tungsten
- Water

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Continuous PS2_CNGS-Beam dumping maximum 3 cycles

PS2_CNGS - old design

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Limits for dumping

<table>
<thead>
<tr>
<th>Beam</th>
<th>Present design</th>
<th>Number of cycles followed by 5 minutes of cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNGS</td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>LHC</td>
<td>steady state</td>
<td></td>
</tr>
<tr>
<td>PS2_CNGS</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>PS2_LHC</td>
<td></td>
<td>4</td>
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<table>
<thead>
<tr>
<th>Beam</th>
<th>Present design</th>
<th>Maximum Protons/Second to reach steady state</th>
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<tbody>
<tr>
<td>CNGS (400GeV)</td>
<td></td>
<td>4.51E+12</td>
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<td>LHC (450 GeV)</td>
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<td>3.93E+12</td>
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**400 GeV steady state dumping**

**450 GeV steady state dumping**

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Dump #3 modifications

• Possible modifications that can be done with a reasonable effort when modifying dump #3 to get it ready as spare.

  – Changing composition to:
    • 270cm Graphite (+20)
    • 80 cm Antico (-20)
    • 50cm Copper
    • 30 cm Tungsten

  Drawback:
  Loss in cleaning efficiency

  Particle flux at the end of the dump
  Neutrons: +8%
  Photons: +11%
  Charged particles: +10%

  But, currently the dump (not including the shielding) absorbs only 155 GeV/p.
Possible improvements

Number of cycles followed by 5 minutes of cooling

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<th>Beam</th>
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<td>CNGS</td>
<td>23</td>
<td>38</td>
<td>165.2%</td>
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<td>steady state</td>
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<td>-</td>
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<td>PS2_CNGS</td>
<td>3</td>
<td>4</td>
<td>133.3%</td>
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<td>PS2_LHC</td>
<td>4</td>
<td>6</td>
<td>150.0%</td>
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Maximum Protons/Second to reach steady state

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<td>120.6%</td>
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<td>LHC (450 GeV)</td>
<td>3.93E+12</td>
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Beam Present
design Modification gain
CNGS 23 38 165.2%
LHC steady state steady state -
PS2_CNGS 3 4 133.3%
PS2_LHC 4 6 150.0%

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400 GeV steady state dumping

450 GeV steady state dumping

97kW
113kW

97kW
113kW

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## Limitations

### Maximum Protons/Second to reach steady state

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### Maximum proton current for steady state operation

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<td>Present design</td>
<td>2.71E+13</td>
<td>1.89E+13</td>
<td>2.16E+13</td>
</tr>
<tr>
<td>Modification</td>
<td>3.26E+13</td>
<td>2.25E+13</td>
<td>2.61E+13</td>
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<tr>
<td>Repetition time [sec]</td>
<td>6</td>
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### Maximum dump intensity 4.5e+13

Any operation below those limits is OK!

### Maximum protons/second to reach steady state

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### Any operation above those limits needs to respect the maximum number of consecutive cycles + cool down time!

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Conclusion
Short-term scenario

• Dump #3 needs to be modified to serve as spare
  – Removal of foil and better Ti coating
  – Intense vacuum firing to clean the graphite
  – Long bakeout in the lab to remove water
  → improving the current Vacuum issues

• Optional:
  – Slight design modification to gain better performance

This can be achieved short-term
Conclusion
Long-term scenario

• A better performance of the dump needs a completely new design
  – This can be achieved with better cleaning efficiency. (TDI for LHC absorbs 200 GeV/proton with the same dimensions)

• About 3 years needed for design and construction

• Costs 0.5-1 MCHF/piece
Further thoughts

• This study was only for the TIDVG!
• Other beam intercepting devices in the SPS
  – TIDH (low energy)
  – TIDP (momentum)
  – TBSJ (injection beam stopper)
  – TBSM (first turn beam stopper)
• Designed in the 70s
• Definite operations limits are not known!
The End